DEFINITION OF A PRE-CRASH SCENARIO TYPOLOGY FOR VEHICLE SAFETY RESEARCH

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ABSTRACT

This paper defines a new pre-crash scenario typology for vehicle safety research based on the 2004 General Estimates System (GES) crash database. The purpose of this typology is to establish a common foundation for public and private organizations to develop and estimate potential safety benefits of effective crash countermeasure systems. Pre-crash scenarios portray vehicle movements and critical events immediately prior to the crash. This new typology consists of a set of 36 pre-crash scenarios representing 99.4% of all police-reported crashes that involve at least one light vehicle (i.e., passenger car, sports utility vehicle, van, mini-van, and light pickup truck). Light-vehicle crashes accounted for about 5,942,000 police-reported crashes in the United States based on 2004 GES statistics. This typology is nationally representative and can be annually updated using national crash databases. This paper quantifies the severity of the scenarios in terms of annual crash frequency, economic costs, and functional years lost. Characteristics of the driving environment, driver, and vehicle are also described.

INTRODUCTION

A number of crash typologies have been developed over the years in support of vehicle safety research. Crash typologies provide an understanding of distinct crash types and scenarios and explain why they occur. They serve as a tool to identify intervention opportunities, set research priorities and direction in technology development, and evaluate the effectiveness of selected crash countermeasure systems. Recently, two crash typologies have been widely used for crash avoidance research in support of the Intelligent Vehicle Initiative (IVI) within the United States Department of Transportation's (U.S. DOT) Intelligent Transportation Systems program: 44-crashes and pre-crash scenarios.

The "44-crashes" typology has been developed by General Motors and adopted by automakers for the design, development, and benefits assessment of potential crash countermeasure technologies [1,2]. This typology identified very specific crash scenarios representing all collisions in the United States and investigated the causes associated with each crash scenario using the 1991 General Estimates System (GES) crash database and samples of 1990-1991 police-reported crashes from the states of Michigan and North Carolina. Shortcomings of this typology include the limited study of state crash data and the amount of effort required to replicate the results using recent crash data.

The U.S. DOT has devised the "pre-crash scenarios" typology based primarily on pre-crash variables in the National Automotive Sampling System crash databases including the GES and Crashworthiness Data System (CDS) [3]. This typology has been utilized to identify intervention opportunities, develop performance guidelines and objective test procedures, and estimate the safety benefits for IVI crash countermeasure systems. Single-vehicle and two-vehicle crashes of common crash types were analyzed to produce the list of representative pre-crash scenarios. Multi-vehicle (> 2 vehicles) crashes were not included in the analysis. Some low-frequency crash types were also excluded such as vehicle failure, non-collision incidents, and evasive action scenarios. The "pre-crash scenarios" typology did not represent 100% of all police-reported crashes.

This paper defines a new typology of pre-crash scenarios for vehicle safety research by combining crash information from both typologies mentioned above. This new typology consists of pre-crash scenarios that depict vehicle movements and dynamics as well as the critical event occurring immediately prior to crashes involving at least one light vehicle (i.e., passenger car, sports utility vehicle, van, mini-van, and light pickup truck). This typology will establish a common foundation for public and private researchers to determine which traffic safety issues should be of first priority to investigate and to develop concomitant crash countermeasure systems. Its main objectives are to:

- Identify all common pre-crash scenarios of all crashes involving at least one light vehicle.
- Quantify the severity of each pre-crash scenario in terms of the frequency of occurrence, economic costs, and functional years lost.

- Portray each scenario by crash contributing factors and circumstances in terms of the driving environment, driver, and vehicle.
- Provide representative crash statistics that can be annually updated using national crash databases.

Next, this paper describes the methodology to identify pre-crash scenarios using GES variables. This is followed by listing the pre-crash scenarios of the new typology. Afterward, each pre-crash scenario is characterized by crash severity, contributing factors, and circumstances. Finally, this paper discusses the national representation and mapping of the new typology to the "44-crashes" typology.

SCENARIO IDENTIFICATION METHODOLOGY

The new crash typology is primarily structured with dynamically-distinct pre-crash scenarios that describe vehicle movements and critical events leading to the crash. The GES Vehicle File contains the Accident Type, Movement Prior to Critical Event, and Critical Event variables that allow the identification of such scenarios [4]. The Accident Type variable categorizes the pre-crash situation. The Movement Prior to Critical Event variable records the attribute that best describes vehicle activity prior to the driver's realization of an impending critical event or just prior to impact if the driver took no action or had no time to attempt any evasive maneuver. The Critical Event variable identifies the circumstances that made the crash imminent. The new typology is derived from separate analyses conducted on single-vehicle, two-vehicle, and multi-vehicle crashes. The GES Event File identifies the first event in a crash, which helps to distinguish pre-crash scenarios in two-vehicle and multi-vehicle crashes.

A coding scheme based on GES variables and codes was devised to identify common pre-crash scenarios representing 100% of all light-vehicle crashes [5]. A total of 46 pre-crash scenarios were initially coded and prioritized in a selected order as listed in Table 1. The new pre-crash scenario typology was then created by querying the 2004 GES and deducting the scenarios in the same order using the process of elimination, and thus avoiding double counting of crashes in each of these scenarios. The list of selected scenarios was prioritized by starting with scenarios associated with crash contributing factors such as vehicle control loss and driver violation of red light/stop sign. Such scenarios result in different crash types. For example, loss of vehicle control due to excessive speed could lead to a vehicle running off the road, rear-ending another vehicle in front of it, or encroaching into another lane and side-swiping an adjacent vehicle. From a crash avoidance perspective, the problem of vehicle control loss is identical in all three cases. A potential crash countermeasure function would detect the excessive speed or the imminent loss of control regardless of what crash type these conditions might lead to. Therefore, scenarios based on crash contributing factors supersede scenarios that represent dynamically-distinct driving situations based on vehicle movements and dynamic states.

PRE-CRASH SCENARIO TYPOLOGY

The new pre-crash scenario typology of all light-vehicle crashes was derived by integrating lists of pre-crash scenarios from single-vehicle, two-vehicle, and multi-vehicle crashes based on 2004 GES statistics. Approximately 5,942,000 police-reported crashes involved at least one light vehicle, which accounted for 96.3% of all crashes in 2004. A total of 10,695,000 vehicles and 15,027,000 people were involved in these light-vehicle crashes resulting in 2,737,000 injured people.

Table 2 ranks pre-crash scenarios of all light-vehicle crashes in descending order in terms of the frequency of occurrence. A total of 36 pre-crash scenarios represent 99.4% of all light-vehicle crashes or 95.7% of all vehicle-type crashes. Further research is needed to identify how many crashes involving medium/heavy vehicles only are represented by this new typology. The top scenario with an individual relative frequency over 10% – lead vehicle stopped – accounts for 16% of all light-vehicle crashes. The following six scenarios with an individual relative frequency between 5 and 10% represent about 40% of all these crashes. The remaining 29 pre-crash scenarios correspond to 43% of all light-vehicle crashes. There are "other" scenarios that only account for 0.6% of all light-vehicle crashes including on-road rollover (0.06%), hit and run (0.09%), no driver present (0.07%), and other non-specific or no-details scenarios.

DESCRIPTION OF SCENARIOS

This section provides a detailed description for each of the 36 scenarios based on the same order as listed in Table 2. The severity of each scenario is quantified in terms of economic costs, functional years lost, number of vehicles involved, number of people involved, and percentage of people who suffered high-level injuries based on the Abbreviated Injury Scale greater than or equal to 3 (AIS 3+): serious, severe, critical, or fatal. The GES does not provide detailed information regarding injury severity based on the AIS coding scheme. Instead, the GES records injury severity by crash victim on the KABCO scale from police crash reports. Police reports in almost every state use KABCO to classify crash victims as K – killed, A – incapacitating injury, B – non-incapacitating injury, C – possible injury, O – no apparent injury, or ISU – Injury Severity Unknown. The KABCO coding scheme allows non-

medically trained persons to make on-scene injury assessments without a hands-on examination. However, KABCO ratings are imprecise and inconsistently coded between states and over time. To estimate injuries based on the MAIS coding structure, a translator derived from 1982–1986 NASS data was applied to the GES police-reported injury profile [6]. The following matrix equation shows the multiplicative factors used to convert injury severity from KABCO to MAIS designations:

$$\begin{bmatrix} MAIS0 \\ MAIS1 \\ MAIS2 \\ MAIS3 \\ MAIS4 \\ MAIS5 \\ MAIS6 \end{bmatrix} = \begin{bmatrix} 0 & 0.01516 & 0.04938 & 0.19919 & 0.92423 & 0.07523 \\ 0 & 0.49183 & 0.79229 & 0.71729 & 0.07342 & 0.70581 \\ 0 & 0.27920 & 0.12487 & 0.06761 & 0.00206 & 0.15708 \\ 0 & 0.16713 & 0.03009 & 0.01509 & 0.00029 & 0.04343 \\ 0 & 0.02907 & 0.00267 & 0.00064 & 0.00001 & 0.01712 \\ 0 & 0.01762 & 0.00069 & 0.00018 & 0.00000 & 0.00134 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} K \\ A \\ B \\ C \\ O \\ ISU \end{bmatrix}$$

It should be noted that K injuries in KABCO are converted only to fatalities and non-K injuries in KABCO are converted to MAIS 0-5 injuries. The National Highway Traffic Safety Administration recommends that fatal crashes and fatalities be extracted from the Fatality Analysis Reporting System (FARS), not GES, since it contains records on all fatal traffic crashes and thus provides a more accurate representation of fatal crashes and fatalities than the sample contained in the GES. This paper, however, counts fatalities from the GES because FARS does not contain the Accident Type and Critical Event variables needed to identify the pre-crash scenarios of the new typology.

Table 3 provides severity information for each scenario. Economic costs of crashes include lost productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, travel delay, property damage, and workplace losses [7]. Functional years lost is a non-monetary measure that sums the years of life lost to fatal injury and the years of functional capacity lost to nonfatal injury [8]. The economic costs in Table 3 are expressed in year 2000 dollar values.

Typical scenarios are described below by driving environment, driver, and vehicle factors that are most frequently reported in GES crash files. The description also lists over-represented factors based on a simple comparison of percentages between factors in each scenario and concomitant statistics from all light-vehicle crashes and driver exposure data. For example, darkness will be over-represented in a pre-crash scenario if 40% of the crashes occur in the dark that accounts for only 25% of the national distance traveled. It is noteworthy that over-represented factors may not be necessarily the most frequent.

1. Lead Vehicle Stopped: Vehicle is going straight in an urban area, in daylight, under clear weather, at an intersection-related junction with a posted speed limit of 56 km/h; and then closes in on a stopped lead vehicle. Vehicle may also be decelerating or starting in traffic lane and closes in on a stopped lead vehicle. In 50% of these crashes, the lead vehicle first decelerates to a stop and is then struck by the following vehicle. This typically happens in the presence of a traffic control device or the lead vehicle is slowing down to make a turn. This particular scenario is closely related to, but distinct from, the lead-vehicle-decelerating scenario (scenario 4). Rural area, intersection-related junction, inattention, speeding, and younger driver (≤ 24 years old) are over-represented.

2. Control Loss without Prior Vehicle Action: Vehicle is going straight or negotiating a curve in a rural area, in daylight, under adverse weather conditions, with a posted speed limit of 88 km/h; and then loses control due to slippery roads and runs off the road. Vehicle action refers to a vehicle decelerating, accelerating, starting, passing, parking, turning, backing up, changing lanes, merging, and making a successful corrective action to a previous critical event. Dark, adverse weather, slippery road, rural area, non-junction, high-speed road, speeding, younger driver, and rollover are over-represented.

3. Vehicle(s) Turning at Non-Signalized Junctions: Vehicle stops at a stop sign in a rural area, in daylight, under clear weather, at an intersection with a posted speed limit of 56 km/h; and then proceeds to turn left or right against lateral-crossing traffic. Rural area, intersection and driveway/alley locations, low-speed road, vision obscured, inattention, female, and younger and older (≥ 65 years old) drivers are over-represented.

4. Lead Vehicle Decelerating: Vehicle is going straight while following another lead vehicle in a rural area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and then the lead vehicle suddenly decelerates. Vehicle may also be decelerating in traffic lane and then closes in on a decelerating lead vehicle. Daylight, adverse weather, rural area, intersection-related junction, high-speed road, inattention, speeding, and younger driver are over-represented.

5. Road Edge Departure without Prior Vehicle Maneuver: Vehicle is going straight or negotiating a curve in a rural area at night, under clear weather, with a posted speed limit of 88 km/h; and then departs the edge of the road at a non-junction area. Vehicle maneuver denotes passing, parking, turning, changing lanes, merging, and successful corrective action to a previous critical event. Dark, rural area, non-junction, alcohol, inattention, speeding, drowsiness, younger driver, and rollover are over-represented.

6. Vehicle(s) Changing Lanes–Same Direction: Vehicle is changing lanes, passing, or merging in an urban area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and then encroaches into another vehicle traveling in the same direction. Non-junction area, high-speed road, inattention, and younger driver are over-represented.

7. Animal Crash without Prior Vehicle Maneuver: Vehicle is going straight or negotiating a curve in a rural area at night, under clear weather, with a posted speed limit greater of 88 km/h; and then encounters an animal at a non-junction location. Dark, rural area, non-junction, and high-speed roads are over-represented.

8. Straight Crossing Paths at Non-Signalized Junctions: Vehicle stops at a stop sign in an urban area, in daylight, under clear weather, at an intersection with a posted speed limit of 40 km/h; and then proceeds against lateral-crossing traffic. Vehicle may also be going straight through an uncontrolled junction and then cuts across the path of another straight-crossing vehicle from a lateral direction. Moreover, both vehicles may first stop and then proceed on straight crossing paths. Rural area, low-speed road, vision obscured, female, and younger and older drivers are over-represented.

9. Running Red Light: Vehicle is going straight in an urban area, in daylight, under clear weather, with a posted speed limit of 56 km/h; and then runs a red light while crossing straight or turning left at an intersection and collides with another straight-crossing vehicle from a lateral direction. Urban area, inattention, female, and younger and older drivers are over-represented.

10. Vehicle(s) Turning–Same Direction: Vehicle is turning left or right at an intersection in an urban area, in daylight, under clear weather, with a posted speed limit of 56 km/h; and then cuts across the path of another vehicle initially going straight in the same direction. Clear weather, dry road, low-speed road, and younger driver are over-represented.

11. Left Turn across Path from Opposite Directions (LTAP/OD) at Signalized Junctions: Vehicle is turning left in an urban area, in daylight, under clear weather, at a signalized intersection with a posted speed limit of 56 km/h; and then cuts across the path of another vehicle crossing straight from an opposite direction. Vehicle may also be turning left across the path of another vehicle that is also turning left from the opposite direction. Intersection, low-speed road, vision obscured, inattention, female, and younger driver are over-represented.

12. Lead Vehicle Moving at Lower Constant Speed: Vehicle is going straight or decelerating in traffic lane in an urban area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and then closes in on a lead vehicle moving at a lower constant speed. Non-junction location, high-speed road, inattention, speeding, and younger driver are over-represented.

13. LTAP/OD at Non-Signalized Junctions: Vehicle is turning left, in daylight, under clear weather, at an intersection without traffic controls, with a posted speed limit of 56 km/h; and then cuts across the path of another vehicle traveling from the opposite direction. Two vehicles may also be traveling in opposite directions and then both vehicles may turn left across their paths. Rural area, intersection and driveway/alley locations, low-speed road, vision obscured, inattention, and younger and older drivers are over-represented.

14. Backing Up into Another Vehicle: Vehicle is backing up or leaving a parked position (backing up) in an urban area, in daylight, under clear weather, at a driveway/alley location, with a posted speed limit of 40 km/h; and then collides with another vehicle. Daylight, driveway/alley and intersection-related locations, low-speed road, vision obscured, inattention, and younger driver are over-represented.

15. Vehicle(s) Not Making a Maneuver–Opposite Direction: Vehicle is going straight or negotiating a curve in a rural area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and then drifts and encroaches into another vehicle traveling in the opposite direction. Dark, adverse weather, wet/slippery road surface, non-level road, rural area, non-junction, alcohol, male, and younger driver are over-represented.

16. Control Loss with Prior Vehicle Action: Vehicle is turning left or right at an intersection-related area, in daylight, under clear weather, with a posted speed limit of 72 km/h; and then loses control due to wet/slippery roads and runs off the road. Vehicle may also be decelerating in the traffic lane or changing lanes and then loses control. Dark, adverse weather, wet/slippery road, intersection-related, speeding, younger driver, and rollover are over-represented.

17. Vehicle(s) Drifting–Same Direction: Vehicle is going straight in an urban area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and then drifts into an adjacent vehicle traveling in the same direction. Vehicle may also drift into another vehicle stopped in traffic lane. High-speed road, speeding, and younger driver are over-represented.

18. Following Vehicle Making a Maneuver: Vehicle is changing lanes or passing in an urban area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and then closes in on a lead vehicle. Vehicle may also be turning right and then closes in on a lead vehicle. Intersection-related location,

inattention, speeding, and younger driver are over-represented.

19. Road Edge Departure with Prior Vehicle Maneuver: Vehicle is turning left or right at an intersection-related location, in a rural area at night, under clear weather, with a posted speed limit of 40 km/h; and then departs the edge of the road. Vehicle may also attempt to change lanes, pass, or enter/leave a parking position and departs the edge of the road. Dark, intersection-related, low-speed road, alcohol, inattention, and younger driver are over-represented.

20. Road Edge Departure While Backing Up: Vehicle is backing up or leaving/entering a parked position (backing up) in an urban area, in daylight, under clear weather, with a posted speed limit of 40 km/h; and then departs the road edge on the shoulder/parking lane in a driveway/alley location. Driveway/alley location, low-speed road, alcohol, inattention, and younger driver are over-represented.

21. Object Crash without Prior Vehicle Maneuver: Vehicle is going straight or negotiating a curve in a rural area, at night, under clear weather, at a non-junction location with a posted speed limit of 88 km/h; and then collides with an object on the road. First harmful events occur on the road, on shoulder/parking lane, or off the road. Dark, rural area, non-junction, high-speed road, alcohol, younger driver, rollover, and hit and run are over-represented.

22. Evasive Action without Prior Vehicle Maneuver: Vehicle is going straight in an urban area, in daylight, under clear weather, at a non-junction location with a posted speed limit of 56 km/h; and then takes an evasive action to avoid an obstacle. First harmful events occur on the road, off the road, or shoulder/parking lane. Driveway/alley and younger driver are over-represented.

23. Vehicle(s) Parking–Same Direction: Vehicle is leaving a parked position or making a U-turn in an urban area, in daylight, under clear weather, with a posted speed limit of 40 km/h; and then encounters another vehicle traveling in the same direction at a non-junction area. Adverse weather, non-junction area, low-speed road, inattention, and younger driver are over-represented.

24. Running Stop Sign: Vehicle is going straight in a rural area, in daylight, under clear weather, with a posted speed limit of 56 km/h; and then runs a stop sign at an intersection. Vehicle may also run a stop sign while turning either left or right. Low posted speed limit (≤ 56 km/h), inattention, and younger and older drivers are over-represented.

25. Non-Collision Incident: Vehicle is going straight in a rural area, in daylight, under clear weather, at a non-junction location with a posted speed limit of 88 km/h; and then a fire starts on board the vehicle. First harmful events encompass fire or explosion, pavement surface irregularities such as potholes, person injured in vehicle or fell from vehicle, thrown or falling object, and other non-collision events. Clear weather, dry road, rural area, non-junction, high-speed road, and vehicle contributing factors are over-represented.

26. Vehicle Failure: Vehicle is going straight or negotiating a curve in a rural area, in daylight, under clear weather, on a dry road with a posted speed limit of 88 km/h; and then loses control due to catastrophic component failure at a non-junction and runs off the road. Failure of tires, brakes, power train, steering system, and wheels contributed to about 95% of these crashes, with tires alone accounting for 62% of vehicle failure crashes. Rural area, non-junction, high-speed road, younger driver, and rollover are over-represented.

27. Pedestrian Crash without Prior Vehicle Maneuver: Vehicle is going straight in an urban area, in daylight, under clear weather, with a posted speed limit of 40 km/h; and then encounters a pedestrian at a non-junction location. Vehicle may also be starting in traffic lane or negotiating a curve. The pedestrian is running onto the road in 36% of overall scenario crashes. Dark, adverse weather, non-junction area, low-speed road, vision obscured, and younger driver are over-represented.

28. Vehicle Turning Right at Signalized Junctions: Vehicle is turning right in an urban area, in daylight, under clear weather, at a signalized intersection with a posted speed limit of 56 km/h; and then turns into the same direction of another vehicle crossing straight initially from a lateral direction. Vehicle may also be turning right at a signalized intersection and then turns into the opposite direction of another vehicle traveling or stopped initially from a lateral direction. Adverse weather, intersection and intersection-related locations, low-speed road, vision obscured, and younger and older drivers are over-represented.

29. Object Crash with Prior Vehicle Maneuver: Vehicle is leaving a parked position at night, in an urban area, under clear weather, at a non-junction location with a posted speed limit of 40 km/h; and then collides with an object on road shoulder or parking lane. Vehicle may also be turning right and collides with an object. Commonly-cited first harmful events are parked motor vehicle and post, pole, or support. Dark, wet/slippery road, urban area, non-junction, low-speed road, alcohol, younger driver, and hit and run are over-represented.

30. Pedalcyclist Crash without Prior Vehicle Maneuver: Vehicle is going straight or starting in traffic lane in an urban area, in daylight, under clear weather,

with a posted speed limit of 40 km/h; and then encounters a pedalcyclist at an intersection. Clear weather, dry road, intersection, low-speed road, vision obscured, and female driver are over-represented.

31. Animal Crash with Prior Vehicle Maneuver: Vehicle is leaving a parked position or passing another vehicle in a rural area at night, under clear weather; and then encounters an animal at a non-junction area. Dark, wet/slippery road, rural area, non-junction, and high-speed road are over-represented.

32. Pedalcyclist Crash with Prior Vehicle Maneuver: Vehicle is turning right or left in an urban area, in daylight, under clear weather, with a posted speed limit of 40 km/h; and then encounters a pedalcyclist at an intersection. Clear weather, dry road, intersection and intersection-related locations, low-speed road, vision obscured, inattention, and younger driver are over-represented.

33. Pedestrian Crash with Prior Vehicle Maneuver: Vehicle is turning left or right in an urban area, in daylight, under clear weather, with a posted speed limit of 56 km/h; and then encounters a pedestrian in the crosswalk at a signaled intersection. Urban area, intersection and intersection-related locations, low-speed road, vision obscured, and inattention are over-represented.

34. Lead Vehicle Accelerating: Vehicle is going straight or starting in traffic lane in an urban area, in daylight, under clear weather, at intersection-related location with a posted speed limit of 72 km/h; and then closes in on an accelerating lead vehicle. Dry road, intersection-related, high-speed road, traffic signal, inattention, speeding, female, and younger driver are over-represented.

35. Vehicle(s) Making a Maneuver–Opposite Direction: Vehicle is passing another vehicle in a rural area, in daylight, under clear weather, at a non-junction with a posted speed limit of 88 km/h; and encroaches into another vehicle traveling in the opposite direction. Vehicle may also be changing lanes or in the middle of a corrective maneuver and encroaches into another vehicle traveling in the opposite direction. Dark, adverse weather, rural area, non-junction, high-speed road, alcohol, vision obscured, inattention, speeding, male, and young driver are over-represented.

36. Evasive Action with Prior Vehicle Maneuver: Vehicle is turning left at an intersection-related location, in an urban area, in daylight, under clear weather, with a posted speed limit of 56 km/h; and then takes an evasive action to avoid an obstacle. Vehicle may also be passing, turning right, or changing lanes and then takes an evasive action to avoid an obstacle. Dark, urban area, intersection-related location, and younger driver are over-represented.

VALIDATION OF NEW TYPOLOGY

A sample of 236 crash police reports were carefully reviewed to ensure that each crash can be assigned to each of the 36 pre-crash scenarios in the new typology. These reports were obtained from the department of motor vehicles in the state of Massachusetts. The dates of these reports spanned from September 2004 through March 2005, which covered some severe winter months with a substantial amount of snowfall. All crashes were successfully mapped to this new pre-crash scenario typology, except for one crash (categorized as "other") in which a car being towed by a truck sideswiped six parallel parked cars. The two most frequent scenarios in the sample corresponded to the top two most frequent scenarios in the United States as listed in Table 2.

The "44-crashes" typology was also mapped to this new pre-crash scenario typology. Most of the 44 crashes are represented either directly or indirectly by the different variations of pre-crash scenarios in the new typology. For instance, one of the 44 crashes addresses emergency vehicles as they pass through signalized intersections on red. This crash is assigned to "running red light" scenario in the new typology even though the analysis of light-vehicle crashes in this report excludes emergency vehicles. However, the GES contains the needed variables to explicitly describe emergency-vehicle crashes that involve police cars, ambulances, or firefighting vehicles. Other crashes in the "44-crashes" typology represent tailgate, pedal miss, and stutter stop rear-end crash scenarios. These scenarios are indirectly classified in the new typology under lead vehicle decelerating, stopped, or accelerating due to the lack of GES variables and codes that refer to these particular events (e.g., tailgate, etc).

CONCLUSIONS

This paper identified and described a novel typology of pre-crash scenarios, which serves as a foundation for vehicle safety research. This typology consists of 37 pre-crash scenarios (including "other") that accounted for approximately 5,942,000 police-reported crashes involving all light vehicles based on 2004 GES statistics. These crashes resulted in estimated economic costs of $119,846,000,000 and 2,769,000 functional years lost. These statistics do not incorporate data from non-police-reported crashes. Excluding the "other" scenario, this new pre-crash scenario typology represents about 99.4% of all light-vehicle crashes.

Ranking the pre-crash scenarios by crash frequency, economic costs, and functional years lost, the following seven dominant scenarios emerged from a combination of these three measures:

- Control loss without prior vehicle action
- Lead vehicle stopped
- Road edge departure without prior vehicle maneuver
- Vehicle(s) turning at non-signalized junctions
- Straight crossing paths at non-signalized junctions
- Lead vehicle decelerating
- Vehicle(s) not making a maneuver - opposite direction

Crash statistics of this new typology should be updated on an annual basis using the GES or CDS so as to ensure the consistency of its scenario ranking and national representativeness of all light-vehicle crashes over time. It is recommended that the crash severity of the updated typology be quantified using values of economic costs and functional years lost from more recent years. Such updates also serve to identify trends in crash statistics and assess effectiveness of new automotive safety technologies in the vehicle fleet such as electronic stability control systems. Some safety systems can affect these crash scenarios by avoiding the crash altogether, others can reduce the harmful effects of the crash. The next challenge is to use these scenarios as a basis for coordinated benefits evaluations for integrated safety systems that can provide improvements in both crash avoidance and crashworthiness without double counting or otherwise over- or under-estimating safety benefits.

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Table 1. Ordered List of Pre-Crash Scenarios

No	Scenario
1	No Driver Present
2	Vehicle Failure
3	Control Loss with Prior Vehicle Action
4	Control Loss without Prior Vehicle Action
5	Running Red Light
6	Running Stop Sign
7	Road Edge Departure with Prior Vehicle Maneuver
8	Road Edge Departure without Prior Vehicle Maneuver
9	Road Edge Departure While Backing Up
10	Animal Crash with Prior Vehicle Maneuver
11	Animal Crash without Prior Vehicle Maneuver
12	Pedestrian Crash with Prior Vehicle Maneuver
13	Pedestrian Crash without Prior Vehicle Maneuver
14	Pedalcyclist Crash with Prior Vehicle Maneuver
15	Pedalcyclist Crash without Prior Vehicle Maneuver
16	Backing Up into Another Vehicle
17	Vehicle(s) Turning – Same Direction
18	Vehicle(s) Parking – Same Direction
19	Vehicle(s) Changing Lanes – Same Direction
20	Vehicle(s) Drifting – Same Direction
21	Vehicle(s) Making a Maneuver – Opposite Direction
22	Vehicle(s) Not Making a Maneuver – Opposite Direction
23	Following Vehicle Making a Maneuver
24	Lead Vehicle Accelerating
25	Lead Vehicle Moving at Lower Constant Speed
26	Lead Vehicle Decelerating
27	Lead Vehicle Stopped
28	LTAP/OD* at Signalized Junctions
29	Vehicle Turning Right at Signalized Junctions
30	LTAP/OD at Non-Signalized Junctions
31	Straight Crossing Paths at Non-Signalized Junctions
32	Vehicle(s) Turning at Non-Signalized Junctions
33	Evasive Action with Prior Vehicle Maneuver
34	Evasive Action without Prior Vehicle Maneuver
35	Rollover
36	Non-Collision Incident
37	Object Crash with Prior Vehicle Maneuver
38	Object Crash without Prior Vehicle Maneuver
39	Hit and run
40	Other - Rear-End
41	Other - Sideswipe
42	Other - Opposite Direction
43	Other - Turn Across Path
44	Other - Turn Into Path
45	Other - Straight Paths
46	Other

LTAP/OD: Left Turn Across Path/Opposite Direction

Table 2. Pre-Crash Scenarios of All Light-Vehicle Crashes

No	Scenario	Frequency	Rel. Freq.
1	Lead Vehicle Stopped	975,000	16.41%
2	Control Loss without Prior Vehicle Action	529,000	8.90%
3	Vehicle(s) Turning at Non-Signalized Junctions	435,000	7.32%
4	Lead Vehicle Decelerating	428,000	7.20%
5	Road Edge Departure without Prior Vehicle Maneuver	334,000	5.62%
6	Vehicle(s) Changing Lanes – Same Direction	338,000	5.69%
7	Animal Crash without Prior Vehicle Maneuver	305,000	5.13%
8	Straight Crossing Paths at Non-Signalized Junctions	264,000	4.44%
9	Running Red Light	254,000	4.27%
10	Vehicle(s) Turning – Same Direction	222,000	3.73%
11	LTAP/OD at Signalized Junctions	220,000	3.71%
12	Lead Vehicle Moving at Lower Constant Speed	210,000	3.53%
13	LTAP/OD at Non-Signalized Junctions	190,000	3.19%
14	Backing Up into Another Vehicle	131,000	2.20%
15	Vehicle(s) Not Making a Maneuver – Opposite Direction	124,000	2.08%
16	Control Loss with Prior Vehicle Action	103,000	1.73%
17	Vehicle(s) Drifting – Same Direction	98,000	1.65%
18	Following Vehicle Making a Maneuver	85,000	1.44%
19	Road Edge Departure with Prior Vehicle Maneuver	68,000	1.14%
20	Road Edge Departure While Backing Up	66,000	1.11%
21	Object Crash without Prior Vehicle Maneuver	55,000	0.92%
22	Evasive Action without Prior Vehicle Maneuver	56,000	0.95%
23	Vehicle(s) Parking – Same Direction	48,000	0.81%
24	Running Stop Sign	48,000	0.81%
25	Non-Collision Incident	46,000	0.77%
26	Vehicle Failure	42,000	0.71%
27	Pedestrian Crash without Prior Vehicle Maneuver	39,000	0.66%
28	Vehicle Turning Right at Signalized Junctions	35,000	0.59%
29	Object Crash with Prior Vehicle Maneuver	30,000	0.51%
30	Pedalcyclist Crash without Prior Vehicle Maneuver	24,000	0.41%
31	Animal Crash with Prior Vehicle Maneuver	23,000	0.39%
32	Pedalcyclist Crash with Prior Vehicle Maneuver	18,000	0.31%
33	Pedestrian Crash with Prior Vehicle Maneuver	17,000	0.29%
34	Lead Vehicle Accelerating	19,000	0.32%
35	Vehicle(s) Making a Maneuver – Opposite Direction	15,000	0.26%
36	Evasive Action with Prior Vehicle Maneuver	13,000	0.22%
37	Other	36,000	0.60%

Table 3. Severity Statistics of Light-Vehicle Pre-Crash Scenarios

Scenario	Economic Cost ($M)*	Functional Years Lost	Vehicles Involved	People Involved	People AIS 3+
Lead Vehicle Stopped	15,388	240,000	2,162,000	3,032,000	0.50%
Control Loss without Prior Vehicle Action	15,796	478,000	596,000	825,000	2.67%
Vehicle(s) Turning at Non-Signalized Junctions	7,343	138,000	872,000	1,212,000	0.71%
Lead Vehicle Decelerating	6,390	100,000	936,000	1,283,000	0.49%
Road Edge Departure without Prior Vehicle Maneuver	9,005	270,000	338,000	456,000	2.79%
Vehicle(s) Changing Lanes – Same Direction	4,247	71,000	635,000	884,000	0.42%
Animal Crash without Prior Vehicle Maneuver	1,632	24,000	311,000	414,000	0.38%
Straight Crossing Paths at Non-Signalized Junctions	7,290	174,000	535,000	765,000	1.21%
Running Red Light	6,627	135,000	528,000	740,000	1.81%
Vehicle(s) Turning – Same Direction	2,810	47,000	446,000	641,000	0.44%
LTAP/OD at Signalized Junctions	5,749	121,000	457,000	664,000	1.16%
Lead Vehicle Moving at Lower Constant Speed	3,910	78,000	445,000	612,000	0.71%
LTAP/OD at Non-Signalized Junctions	5,137	113,000	389,000	558,000	1.24%
Backing Up into Another Vehicle	947	9,000	261,000	363,000	0.13%
Vehicle(s) Not Making a Maneuver – Opposite Direction	6,407	206,000	232,000	330,000	2.58%
Control Loss with Prior Vehicle Action	1,970	49,000	135,000	192,000	1.43%
Vehicle(s) Drifting – Same Direction	1,383	37,000	235,000	330,000	0.58%
Following Vehicle Making a Maneuver	1,212	18,000	180,000	249,000	0.50%
Road Edge Departure with Prior Vehicle Maneuver	1,144	34,000	70,000	98,000	1.42%
Road Edge Departure While Backing Up	350	6,000	66,000	95,000	0.27%
Object Crash without Prior Vehicle Maneuver	687	19,000	55,000	76,000	1.12%
Evasive Action without Prior Vehicle Maneuver	1,349	36,000	99,000	137,000	1.23%
Vehicle(s) Parking – Same Direction	623	11,000	95,000	125,000	0.45%
Running Stop Sign	1,310	28,000	93,000	133,000	1.33%
Non-Collision Incident	592	13,000	82,000	112,000	0.56%
Vehicle Failure	1,051	26,000	53,000	89,000	1.78%
Pedestrian Crash without Prior Vehicle Maneuver	4,022	144,000	42,000	98,000	5.74%
Vehicle Turning Right at Signalized Junctions	355	4,000	71,000	98,000	0.27%
Object Crash with Prior Vehicle Maneuver	155	3,000	30,000	34,000	0.35%
Pedalcyclist Crash without Prior Vehicle Maneuver	1,301	39,000	25,000	58,000	3.27%
Animal Crash with Prior Vehicle Maneuver	120	2,000	24,000	27,000	0.36%
Pedalcyclist Crash with Prior Vehicle Maneuver	523	11,000	19,000	48,000	1.65%
Pedestrian Crash with Prior Vehicle Maneuver	843	24,000	18,000	41,000	2.87%
Lead Vehicle Accelerating	273	4,000	40,000	54,000	0.55%
Vehicle(s) Making a Maneuver – Opposite Direction	943	32,000	30,000	40,000	3.16%
Evasive Action with Prior Vehicle Maneuver	198	4,000	25,000	36,000	0.64%
Other	764	21,000	65,000	78,000	1.16%
Total	119,846	2,769,000	10,695,000	15,027,000	0.97%

*: Expressed in year 2000 dollar value